X-ray Binaries in Nearby Galaxies

Vicky Kalogera
Northwestern University

with

Chris Belczynski (NU)

Andreas Zezas and Pepi Fabbiano (CfA)

XLF observations: questions and puzzles

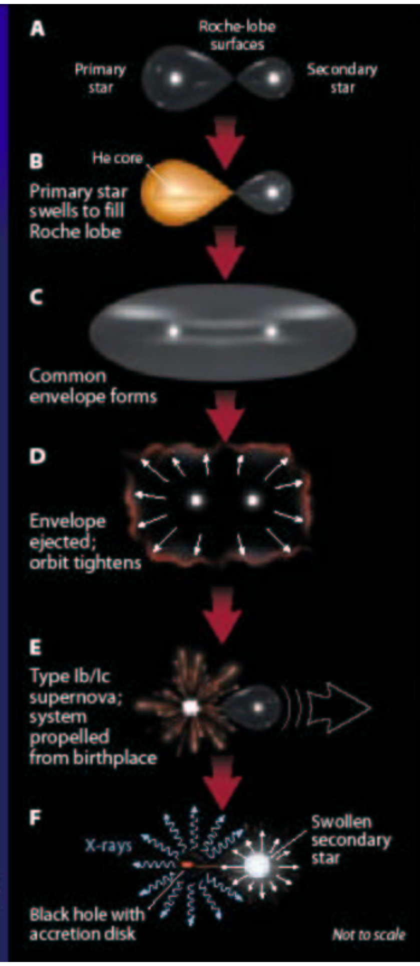
★ *What determines the shape of XLFs ?*
Is it a result of a blend of XRB populations ?
How does it evolve ?

★ *Are the reported breaks in XLFs real*
or due to incompleteness effects ?
If they are real, are they caused by
> different XRB populations ? (Sarazin et al. 2000)
> age effects ? (Wu 2000; Kilgard et al. 2002)
> something else ?


XLF observations:
questions and puzzles
Can the XLF properties (shapes, numbers) be used as star-formation indicators ?
e.g., IMF, metallicity, star-formation rate, or age ?
What is the origin of the ULXs ?
Can we explain them as `normal' BH-XRBs or the hypothesis of intermediate-mass BH is necessary ?
What is the role of XRB formation in globular clusters ?
How different are the XLF properties of dynamically formed XRBs ?


Theoretical Modeling
Current status: observationally-driven
observations present us with a challenge and opportunity for progress in the study of global XRB population properties.
Population Synthesis Calculations: necessary
Basic Concept of Statistical Description:
evolution of an ensemble of binary and single stars with focus on XRB formation and their evolution through the X-ray phase.

How do X-ray binaries form ?



primordial binary

Common Envelope: orbital contraction and mass loss

NS or BH formation

X-ray binary at Roche-lobe overflow

courtesy
Sky & Telescope
Feb 2003 issue

Population Synthesis Elements

- *Star formation conditions:*
  - *time and duration, metallicity, IMF, binary properties*
- *Modeling of single and binary evolution*
  - *mass, radius, core mass, wind mass loss*
  - *orbital evolution: e.g., tidal synchronization and circularization, mass loss, mass transfer*
  - *mass transfer modeling:*
    stable driven by nuclear evolution or angular momentum loss
    thermally unstable or dynamically unstable
  - *compact object formation: masses and supernova kicks*
  - *X-ray phase: evolution of mass-transfer rate and X-ray luminosity*

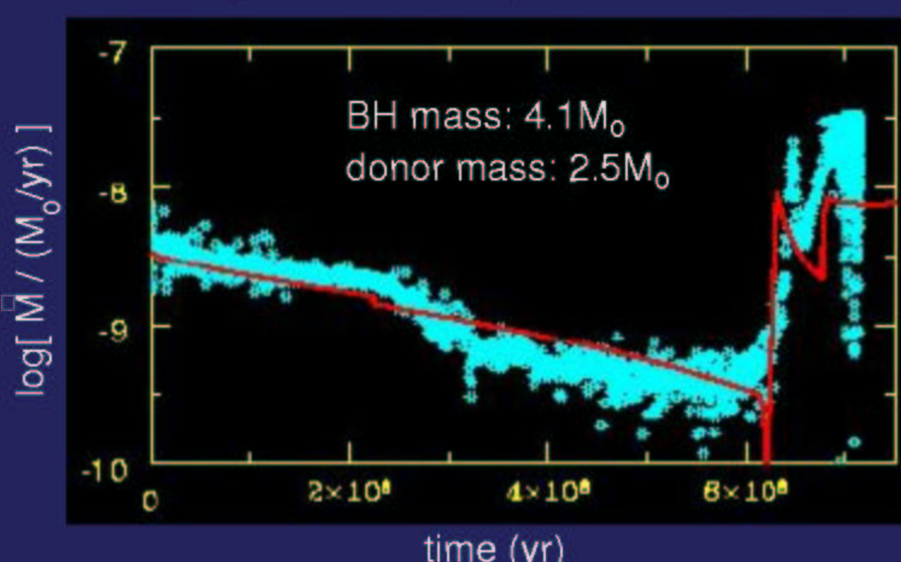
Population Synthesis with 'StarTrack'

Belczynski et al. 2001,2003

- *Single-star models from Hurley et al. 2000*
- *Tidal evolution of binaries included*
  - > *important for wind-fed X-ray binaries*
    tested with measured P_{orb} contraction
    (e.g., LMC X-4; Levine et al. 2000)
- *Mass transfer calculations ($\dot{M}$ and L_X)*
  - > *wind-fed: Bondi accretion*
  - > *Roche-lobe overflow:*
    $\dot{M}$ based on radial response of donor and Roche lobe to mass exchange and possible loss from the binary (tested against detailed mass-transfer calculations)
  - > *also included: Eddington-limited accretion (testable) thermal-time scale mass transfer, transient behavior*

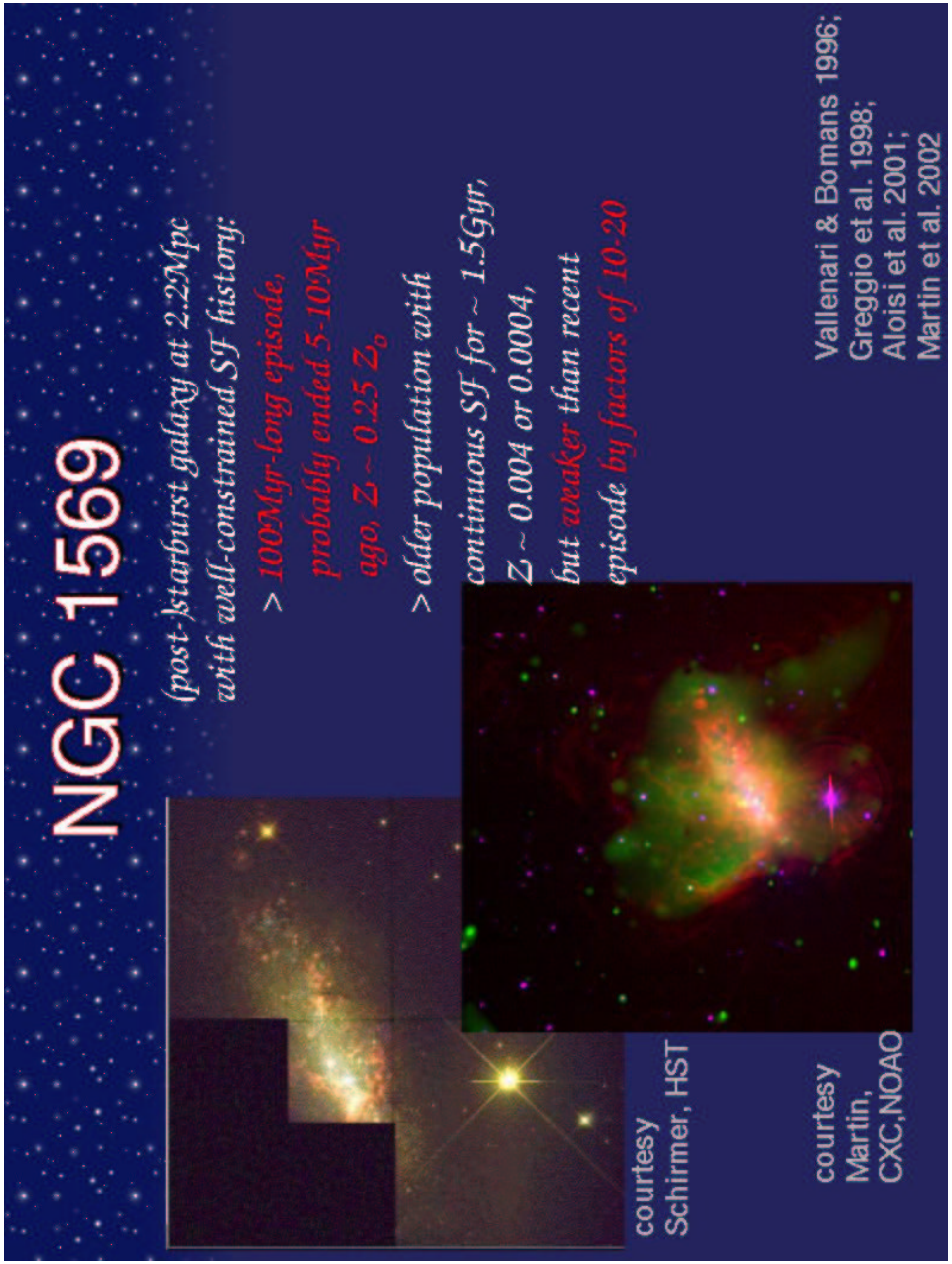
Example of Mass-Transfer Calculation

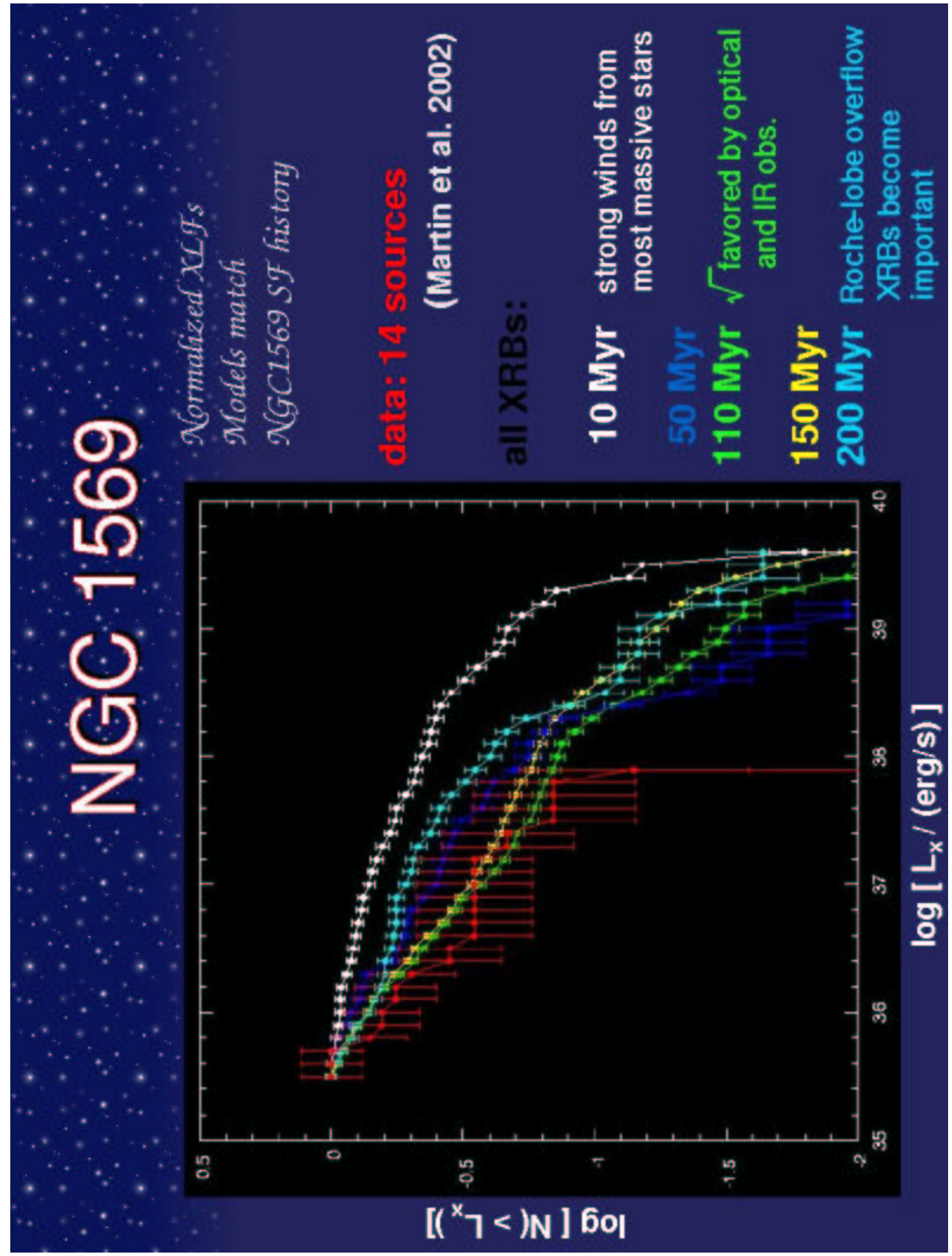
Comparison between a detailed caclulation with a full stellar evolution code (N. Ivanova) and the semi-analytic treatment implemented in *StarTrack*

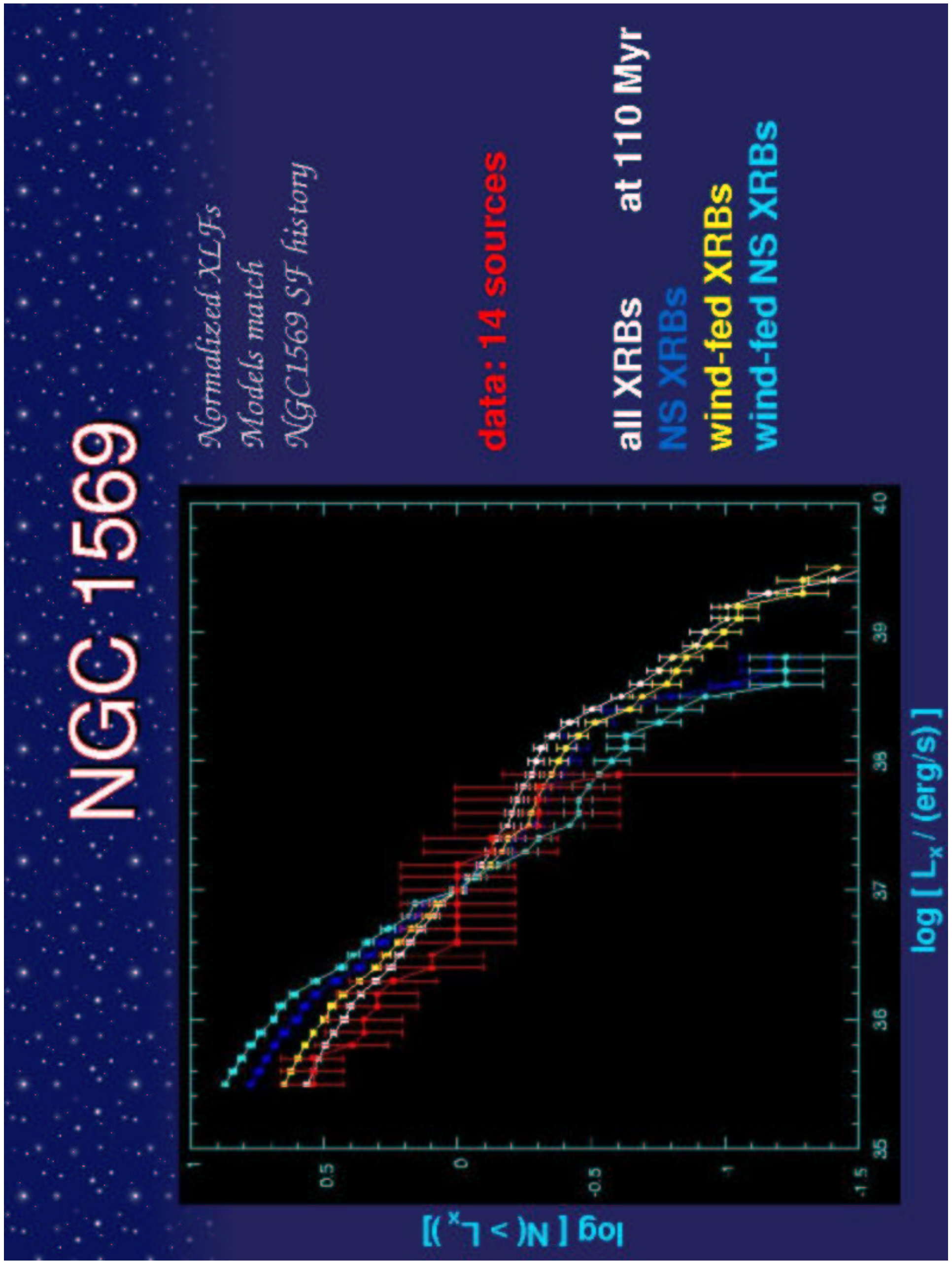


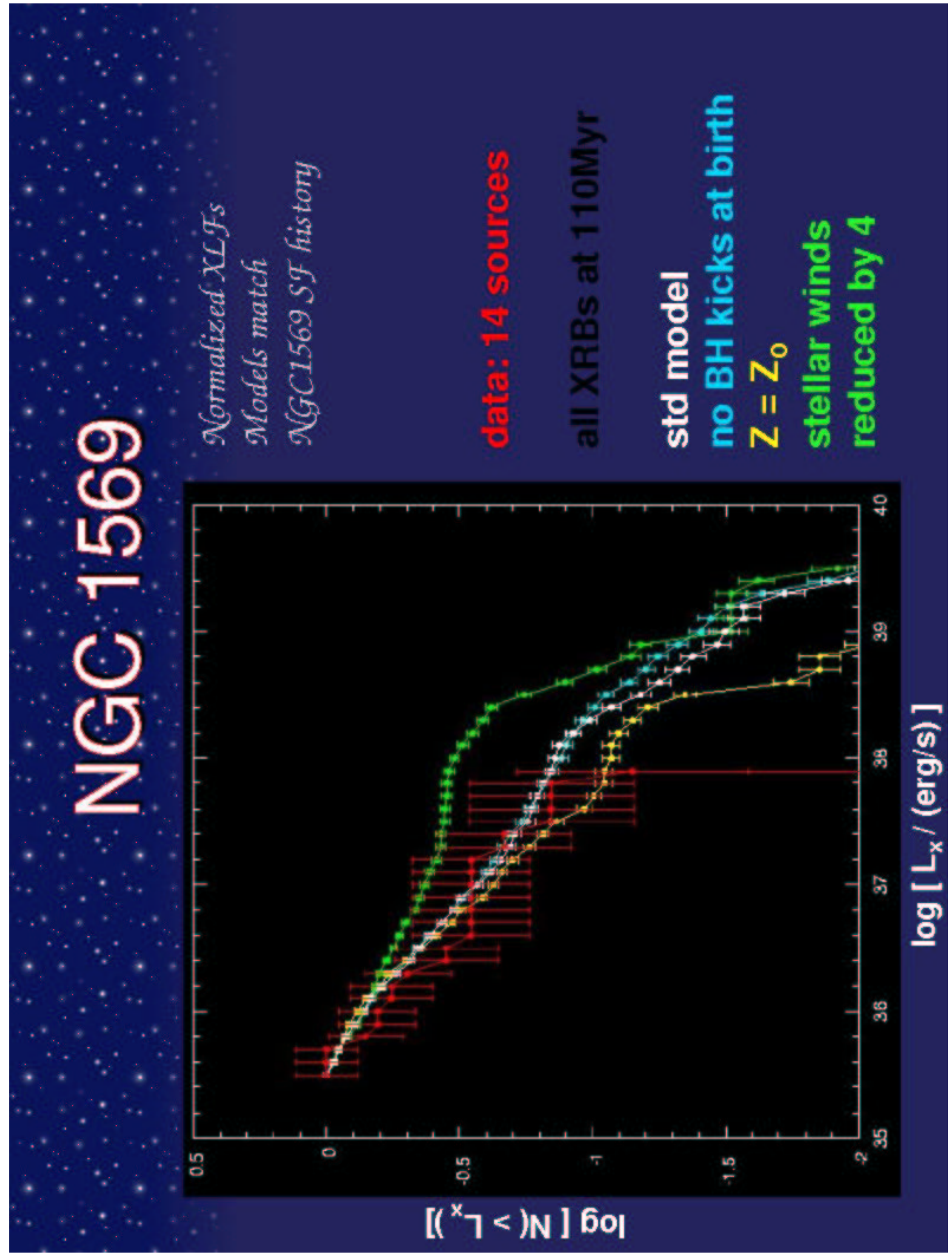
semi-analytic calculation most appropriate for statistical modeling of large binary populations

choice of masses from Beer & Podsiadlowski 2002 Results in very good agreement (within 20-50%)

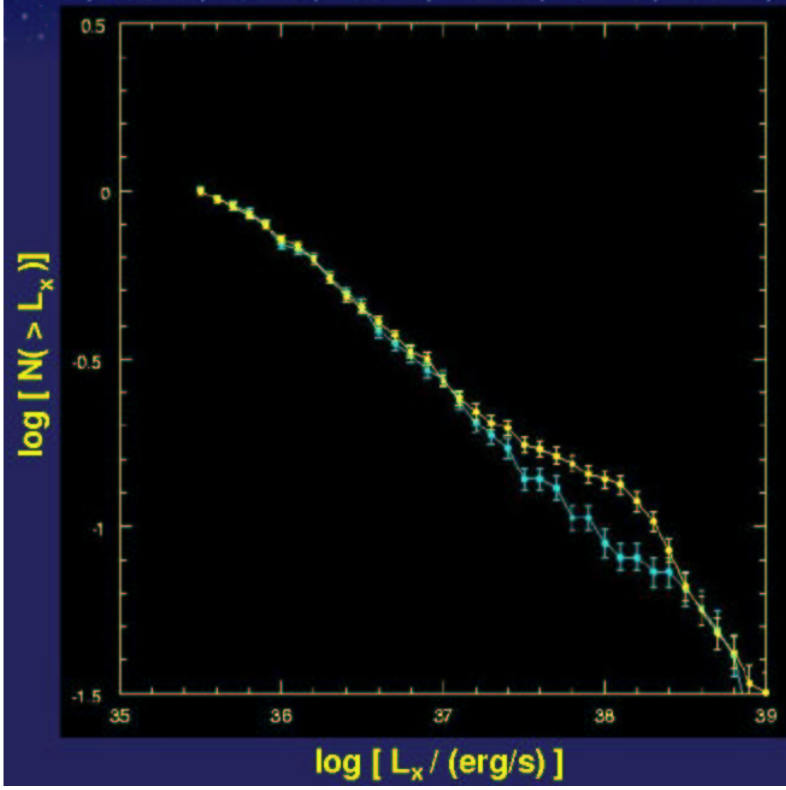

NGC 1569
(post-)starburst galaxy at 2.2Mpc
with well-constrained SF history:
> 100Myr-long episode, probably ended 5-10Myr ago, Z ~ 0.25 $Z_\odot$
> older population with continuous SF for ~ 1.5Gyr, Z ~ 0.004 or 0.0004, but weaker than recent episode by factors of 10-20
Vallenari & Bomans 1996; Greggio et al. 1998; Aloisi et al. 2001; Martin et al. 2002
courtesy Schirmer, HST
courtesy Martin, CXC,NOAO


NGC 1569
Normalized XLFs
Models match NGC1569 SF history
data: 14 sources (Martin et al. 2002)
all XRBs:
10 Myr strong winds from most massive stars
50 Myr
110 Myr √ favored by optical and IR obs.
150 Myr
200 Myr Roche-lobe overflow XRBs become important
log [N(> L_x)]
log [L_x / (erg/s)]
35
36
37
38
39
40
0.5
0
-0.5
-1
-1.5
-2


NGC 1569
Normalized XLFs
Models match
NGC1569 SF history
data: 14 sources
all XRBs at 110 Myr
NS XRBs
wind-fed XRBs
wind-fed NS XRBs
log [N(> L$_x$)]
log [L$_x$ / (erg/s)]


NGC 1569
Normalized XLFs
Models match
NGC1569 SF history
data: 14 sources
all XRBs at 110Myr
std model
no BH kicks at birth
Z = Z$_o$
stellar winds
reduced by 4
log [N(> L$_x$)]
log [L$_x$ / (erg/s)]

XLF slopes and breaks



Normalized XLFs
Models match
NGC1569 SF history

all XRBs

Eddington-limited accretion

no Eddington limit imposed

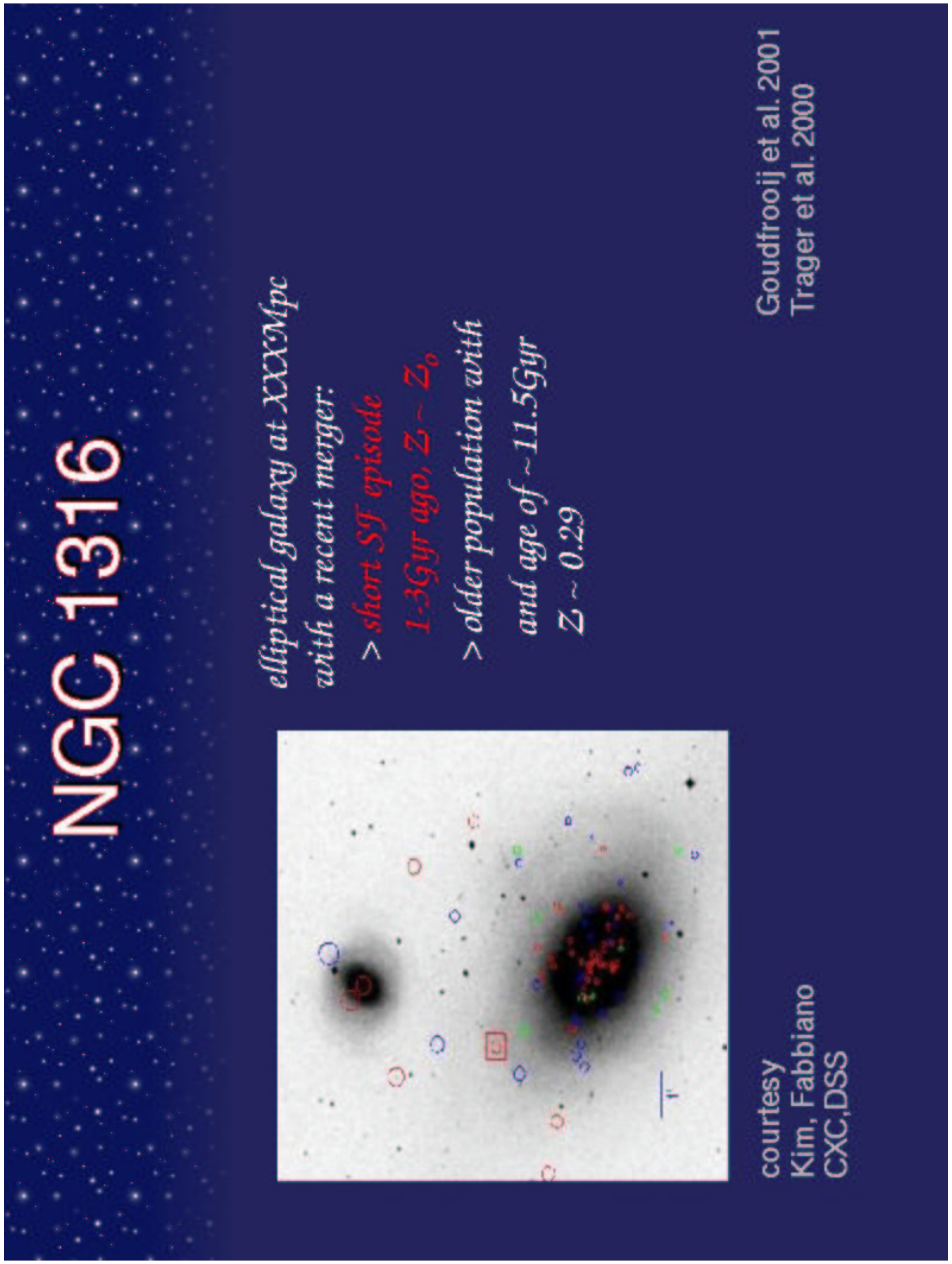
Arons et al. 1992...
Shaviv 1998...
Begelman et al. 2001...

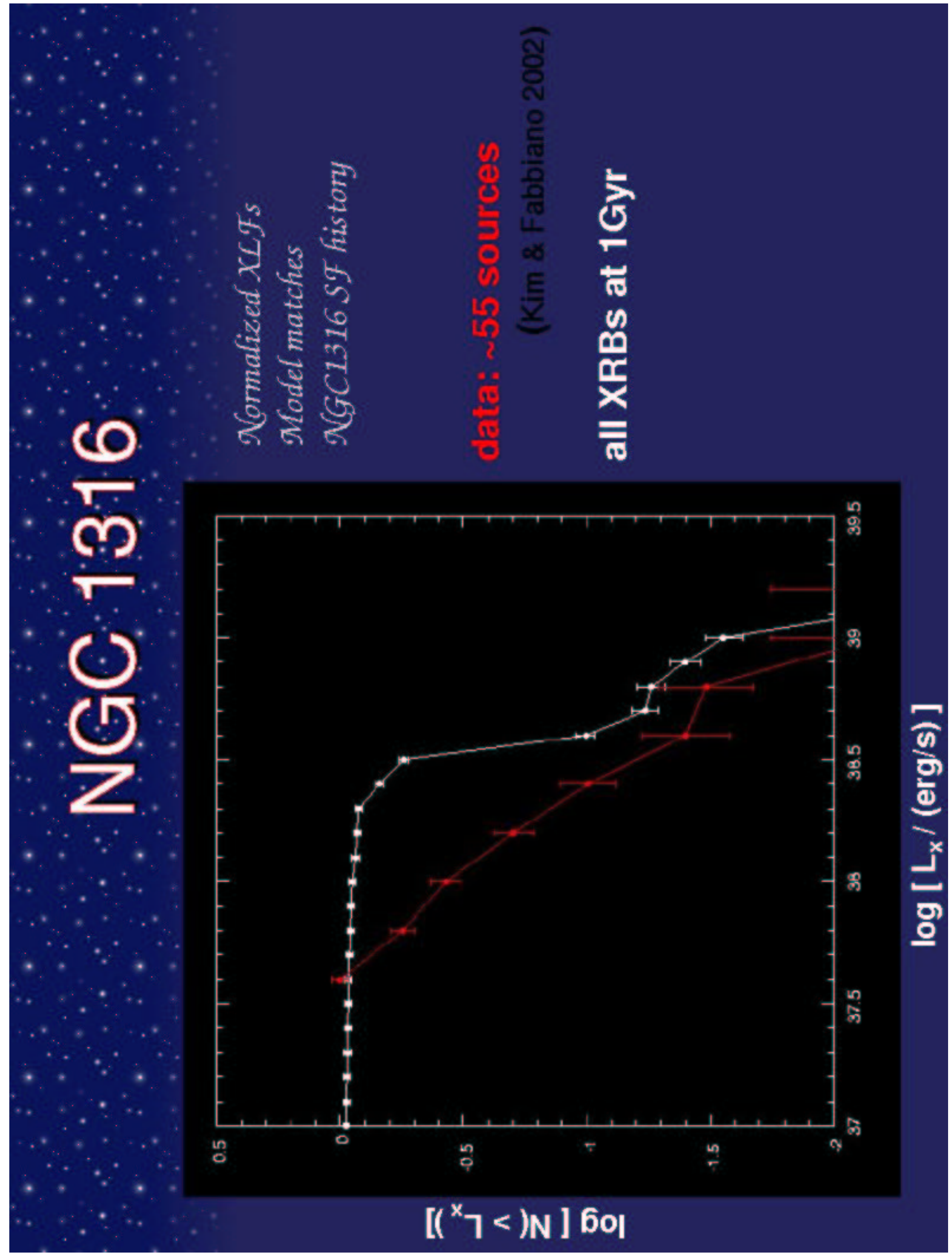
Initial Conclusions ...

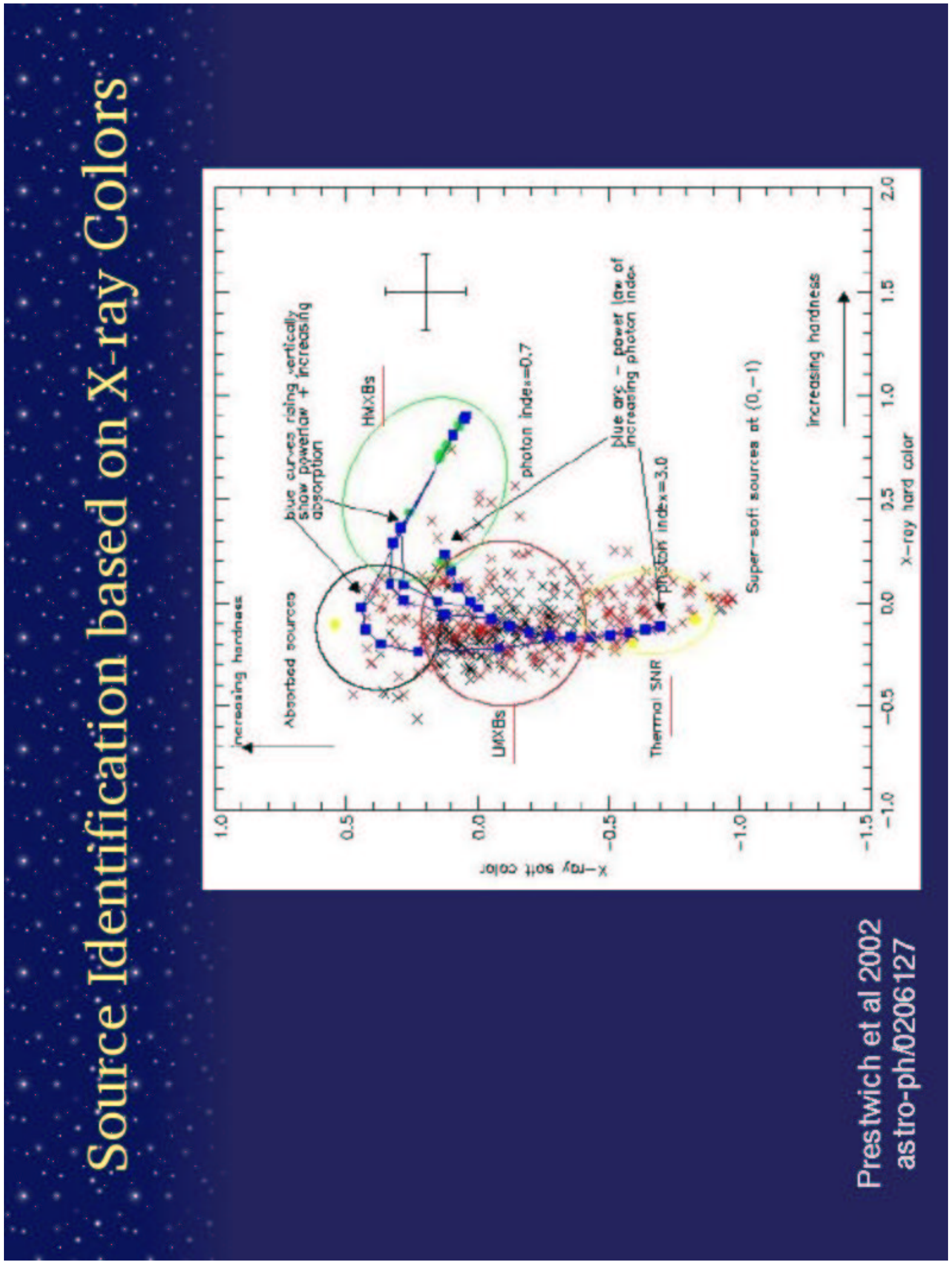
- *Current understanding of XRB formation and evolution produces XLF properties consistent with observations*
- *Model XLFs can be used to confirm star-formation properties, e.g., age and metallicity*
- *Shape of model XLFs appear robust against variations of most binary evolution parameters*
- *'Broken' power-laws seem to be due either to aging pops or Eddington-limited accretion* > *lack of breaks in young populations possibly argues against the relevance of a limit*


What's coming next ...
Choose a sample of galaxies with relatively well-understood star-formation histories and > indentify XRB models that best describe the XLF shape > use the results to 'calibrate' population models for different galaxy types (spirals, starburst, ellipticals) and derive constraints on the star-formation history of other galaxies
For a given SF or SN rate obtained from optical/IR obs, use the number of XRBs, to constrain binary evolution parameters that affect the absolute normalization of the XLF but not its shape (NOTE: observational selection effects)


What's coming next ...
Physical origin of ULXs: > Can their numbers and luminosities be explained by XRBs with black holes ?
> Are they associated with transient systems OR binaries transferring mass on the thermal time scale with anisotropic emission ?
> How does their presence correlate with metallicity and age of the population ?
How are XLFs different if dynamical processes are important ? (work by N.Ivanova with Belczynski, Rasio, VK)


NGC 1316
elliptical galaxy at XXXMpc
with a recent merger:
> short SF episode
1-3Gyr ago, Z ~ Z_o
> older population with
and age of ~11.5Gyr
Z ~ 0.29
Goudfrooij et al. 2001
Trager et al. 2000
courtesy
Kim, Fabbiano
CXC,DSS


NGC 1316
Normalized XLFs
Model matches
NGC1316 SF history
data: ~55 sources
(Kim & Fabbiano 2002)
all XRBs at 1Gyr
log [N(> L_x)]
log [L_x / (erg/s)]
0.5
0
-0.5
-1
-1.5
-2
37
37.5
38
38.5
39
39.5


Source Identification based on X-ray Colors
Increasing hardness
Absorbed sources
blue curves rising vertically show powerlaw + increasing absorption
HMXBs
photon index=0.7
blue arc – power law of increasing photon index
photon index=3.0
LMXBs
Thermal SNR
Super-soft sources at (0,−1)
Increasing hardness
X-ray hard color
X-ray soft color
Prestwich et al 2002
astro-ph/0206127